Inventiveness as Belief Revision and a Heuristic Rule of Inventive Design *

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Abstract. The notion of *inventive* belief revision, as the opposite to the notion of *trade-off* belief revision, is introduced. A heuristic rule of identifying the beliefs to be revised, is proposed. It is shown that some well known inventions might be arrived at with the help of this rule, which means that the rule can be used as a powerful tool in computer aided inventive design.

Keywords: belief revision, innovation modeling, computer aided inventive design, logics in artificial intelligence.

1 Introduction.

As is known, design of any system usually starts at the high level design followed by detailed design consisting of a number of iterrations, each of which refines the previous one. During high level design, a designer may set objectives $O_1, O_2, \ldots, O_n$, none of which seem to be contradictory at this stage. However, in the course of subsequent refinements, the designer may freely or otherwise make assumptions $a_1, a_2, \ldots, a_m$ about ways of achieving the objectives and/or face some natural constraints $c_1, c_2, \ldots, c_k$, in view of which the objectives may become contradictory.

For example, suppose that one is going to design an aircraft capable to carry 200 passengers (objective O_1) a distance of 10,000 km (objective O_2) without a landing (objective O_3) at a speed of 700 km/h (objective O_4). These objectives are obviously not contradictory in themselves. However, if one decides to equip the aircraft with gas turbine engines (assumption a_1), then it turns out that in order to achive the objectives, the engines' propellers have to be 9 meters long. In order to accomadate these huge propellers, the aircraft's undercarriage legs must be inadmissibly long and, therefore, too weak, which makes landing and

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taking off impossible. Thus, the assumption a_1 makes the objectives O_1, O_2, O_3, and O_4 contradictory.

When a designer encounters such a contradiction, he may choose to compromise some objectives. It is called *trade-off design*. In the above case, the trade-off design could result in compromising either speed, the distance of flight without landing, or the desired payload.

Trade-off design fits well into the paradigm of the AGM belief revision [2]. Indeed, the designer has a specification (spec) on the system to be designed. The spec includes objectives and assumptions. The logical inferences coupled with the required calculations reveal an inconsistency in the spec, and the designer needs to revise it in order to make it consistent.

However, besides trade-off design there is also *inventive design* in which designer finds a solution without compromising objectives in spite of contradictions [1]. For example, in the above case with aircraft, a possible *inventive solution* is to equip the engine with two small coaxial propellers rotating in the opposite directions rather than to equip it with one 9 m long propeller. Just this solution was implemented on some gas turbine airliners in the 1950s. This invention allowed the designers to achive objectives O_1, O_2, O_3, and O_4 without compromising.

In a sense, it is also belief revision, namely revision of the assumption that an engine has *one* propeller. However, unlike assumption a_1, this assumption has not been made explicitly. It was a tacit unrealizable assumption taken by the designers for granted. The number of such unrealizable assumptions is astronomically big in any design and even a very thorough specification on a system cannot list all of them.

As far as I know, no work has been done on belief revision when only a portion of the belief system is realizable. In other words, when the database does not contain all the pieces of information and there are hidden pieces which are encripted in the rules of deriving inferences from the database. Moreover, to the best of my knowledge, no other rules of reasoning distinct from purely logical inferences have been taken into account in works on belief revision.

I call *inventive belief revision* such belief revision where only some pieces of information are explicitly represented in the database and most pieces are implicitly hidden in the rules of deriving consequences, which besides logical inferences may include calculations and other procedures.

In this paper, I propose some rules of inventive belief revision and show how they could be used to solve challenging inventive problems of the past.

2 Resolving contradictions by separating contradictory requirements

One of the major problems in belief revision is how to find that particular belief, which should be retracted in view of the discovered inconsistency in the belief system. Even when the belief system is finite and all beliefs are explicitly stated, it is a difficult problem because usually there is no unique solution: the consistency can be restored by retracting one of many possible pieces of information. Most publications on belief revision study the latter problem of making a choice amongst equally possible revisions rather than the problem of identifying all possible revisions. For finite belief systems, this is justified because the set of all possible revisions can be computed either way (say, by a brute force algorithm).

On the contrary, in the inventive belief revision, the main problem is not that of choice but of identifying some hidden assumptions, alteration of which leads to a solution. That is why, I am focusing here on proposing some vehicle of transition from contradictory requirements encountered in the course of design process to the sought for hidden assumptions causing the contradiction.

To this end, let us take a closer look at the above example with airplane. The contradictory requirements that the designers faced in that instance, were as follows: *the length of the engine's propeller should not exceed some limit (set by the the reliability of the undercarriage legs) and should exceed it (in order to achive the objectives* O_1, O_2, O_3, O_4*).* In the solution, these contradictory requirements (namely, the length should not exceed some limit and the length should exceed it) turned out to be separated as follows: the length of *a single* engine's propeller did not exceed the limit but the length of *all* the engine's propellers did exceed the limit. Such a separation of the contradictory requirements automatically implied that an engine should have had more than one propeller, which was the desired revision of a tacit unrecognizable assumption that an engine had one propeller only.

It is easily seen that the contradiction itself contained no hint on what hidden assumption to revise, whereas the separation clause clearly pointed out to such an assumption. On the other hand, the separation clause could be obtained from the contradiction clause by inserting the *opposite* attributive words *single* and *all* into the opposite portions of the contradiction clause followed by the corresponding grammatical adjustment of other words. Indeed, the above contradictory requirements to the length of the engine's propeller imply the following contradiction clause: *the length of the engine's propeller does not exceed the limit and the length of the engine's propeller does exceed the limit.* By inserting the opposite words *single* and *all* in the opposite portions of this clause and by entailing grammatical changes in other words, we obtain the separation clause: *the length of a single engine's propeller does not exceed the limit and the length of all the engine's propellers exceeds the limit.* The insofar subconsious assumption on the number of the engine's propellers (which should be revised in order to solve the above aircraft problem) is now logically derivable from this clause.

Thus, we see that although it may be very difficult to recognize the hidden assumption, which causes contradiction, from contradiction itself, it is very easy to recognize it from a separation clause, which can be obtained from the former one in a formal way. Our next objective is to describe this formalism.

Let S be the design belief system that includes the objectives and assumptions (both explicit and implicit). Suppose that the design process runs into a contradiction: $S \vdash R(A)$ and $S \vdash \neg R(A)$, where $R(A)$ means a requirement R to an object/subsystem A of the system to be designed. Let w and w^* be some opposite/dual attributive words about object/system A, and let $w \cdot A$ and $w^* \cdot A$ means that the word w and the word w^* is applied to A respectively. Then $S \dot{-} [R(w \cdot A) \& \neg R(w^* \cdot A)]$ are those assumptions, which should be retracted from S, where $\dot{-}$ means the contraction function [2].

I would like to demonstrate this rule on a few more examples.

3 Examples

3.1 From the history of triode

When Marconi succeded in sending Morse code messages consisting of "dots" and "dashes" by radio waves, many inventors started to search for ways of broadcasting speech and music. The main problem here was that the signals generated in receivers by the radio waves were so weak that even "dots" and "dashes" were bearly distinguishable not to mention distinguishing the sounds of speech and music. Thus, the attempts to design a music/speech receiver had run into the contradiction: the electrical signals in the receiver should be strong enough (in order to distinguish the complex sounds of speech and music) but they are too weak [3].

A possible separation sentence for this contradiction is as follows: the *controlling* signals are weak but the *controlled* signals are strong. Another separation sentence could be like this: the *modulating/shaping* signals are weak but the *modulated/shaped* signals are strong. Both sentences indicate that the assumption that the detected signals are directly fed into the speakers should be revised. This realization drives the thought in the direction of the idea of triode: weak detected signals should control and thereby shape strong signals which are fed into speakers. As is known, Lee De Forest achived it by placing the third electrode between two electrodes of the electrone tube (diode) and by applying the weak signals to the third electrode and feeding the strong signals from the other two electrodes into the speaker. He patented the triode in 1907 and soon had been able to broadcast a live Metropolian Opera performance of Enrico Caruso.

3.2 From the history of feedback curcuit

Amplification of signals by triodes was, however, not safficient for high quality broadcasting. That is why Lee De Forest started to build the cascades of triodes by feeding the output from the plate of one tube to the grid of the second, and the output of the second to the grid of the third, and so forth. This, however, led to the enormously big receivers.

Thus, the attempts to build a small high quality receiver run into the contradiction: there should be a cascade of triodes in order to get the high qulity receiving and there should not be a cascade in order to have a small receiver. The separation clause here looks as follows: there is no a cascade *in space* but there is a cascade *in time.* In other words, the output of a single triode should be iteratively fed into its own grid. That was the idea of the feedback circuit patented by Edwin Howard Armstrong in 1912 [4].

3.3 From the history of absorption refrigerator

At the beginning of the XX century the problem of creating a refrigerator without compressor and other moving parts attracted attention from many famous inventors and scientists including even Einstein [5]. The main difficulty here was that in order to get rid of compressor, the pressure in evaporator had to be higher than in condenser. However, in order for a refrigerator to cool, the pressure in evaporator has to be lower than in condenser.

Thus, we have a contradiction, a possible separation clause of which looks as follows: *the total* pressure in evaporator is higher than in condenser but *the partial* pressure of the cooling agent in evaporator is lower than in condenser.

Just this idea was implemented by the Swedish inventor Carl Munters in 1922 when he built the first refrigerator without mechanically moving parts [5].

4 Conclusion

In this paper, I presented a formal rule for generating a sentence, from which the sought for revision of the design belief system is almost obvious. The rule is empirical and cannot be proven mathematically (as is the case with the laws of nature but I stop shortly from calling this rule a law). The rule can be demonstrated on numerous examples from the history of technology that does not imply that the past inventions, which it explains, were done by making use of this rule. One can arrive at a correct answer not necesserily in a logical way but by chance that does not mean that there is no logic to help to find a correct answer. Ultimately, people found correct answers to many questions long before Aristotle put forward any rules of logic (which he also discovered empirically) but since then, the procedures of drawing conclusions were significantly simplified and made less error prone (for those who studied and adhered to his logic).

Analogously, the procedure of navigating amongst contradictions (which is the essense of engineering design) can be grossly formalized and simplified by making use of the proposed rule. The only element of uncertainty (or freedom if one likes) which is present in the rule is how to find the proper opposite/dual words to insert into the proposition and the contraposition respectively. This uncertainty can be further decreased by analysis of plausible separation clauses of the past inventions and compiling a thesaurus of such words. Coupled with such a thesaurus, the above rule can be turned into a powerful tool of *inventive* reasoning in artificial intelligence. It has been successfully tested in the courses on inventive creativity conducted by the author and employed by many graduates of the courses in their daily practices.

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